EBIS Overview

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Presentation Overview

ELECTRON BEAM ION SOURCE

- Introduction
- Test EBIS Results
- R&D Plan
- Status of the RHIC EBIS technical design

Introduction

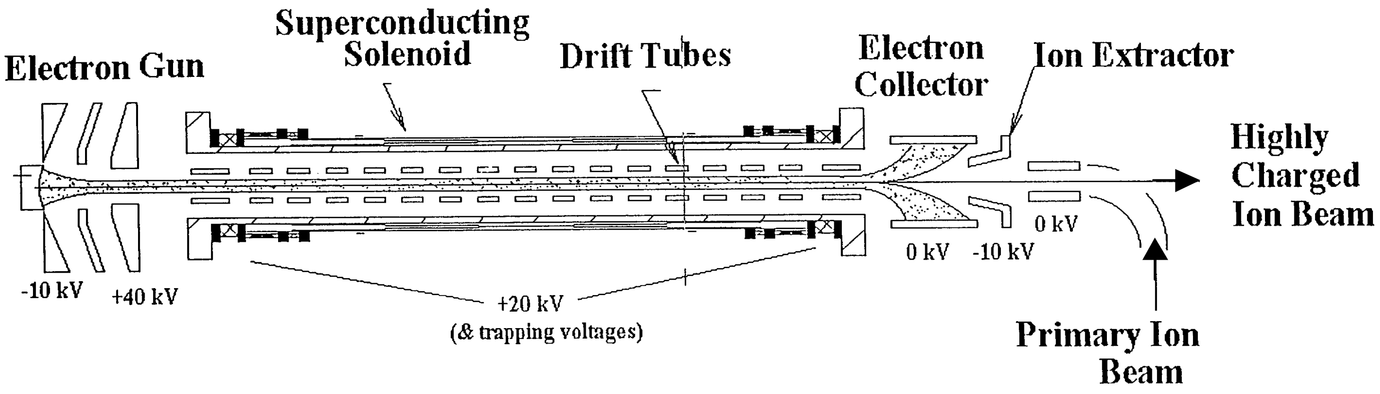
- Experience with the BNL Test EBIS has shown that an EBIS to supply highly charged ions to the Relativistic Heavy Ion Collider (RHIC) and the NASA Space Radiation Laboratory (NSRL) can be built.
  - Test EBIS operation with 10A electron beams required for RHIC EBIS has been achieved.
  - The ion output scales with length, ion charge state is achieved within design confinement times, and the ion electron system has been shown to be stable for ion trap length up to 107cm.

- The RHIC EBIS design will be very similar to the present Test EBIS operating at BNL.

- No significant improvement in performance is required, other than the straightforward scaling of ion output with an increase in trap length.

- Beyond this, changes to the Test EBIS design, which was a device built to demonstrate feasibility, will make the RHIC EBIS an “operational” device, i.e. simpler to maintain, and more reliable due to increased engineering margins on components.

EBIS principle of operation

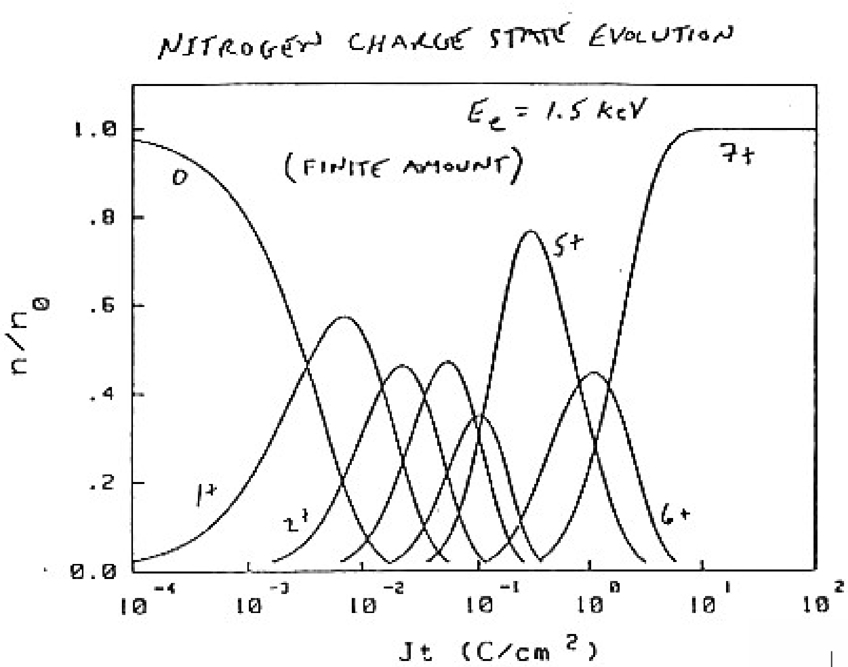


Yield of ions in charge state q:

$$N_q = \frac{I_e \times L}{q \times \sqrt{V_e}} \times K_1 \times K_2$$

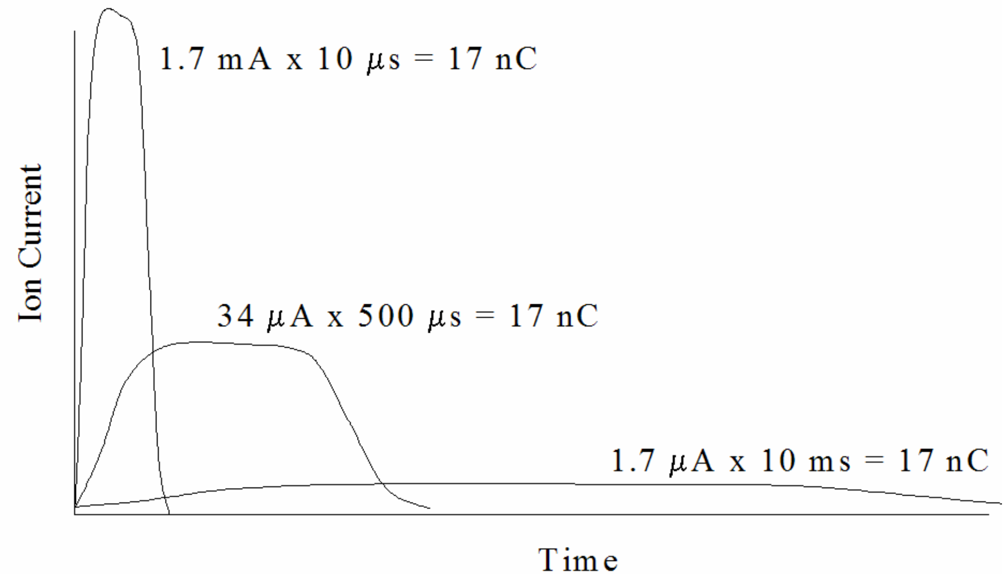
I_e=electron beam current
K_1=neutralization factor
V_e=electron beam voltage
K_2=fraction in desired charge state
L=trap length

Radial trapping of ions by the space charge of the electron beam.
Axial trapping by applied electrode electrostatic potentials.
Ion output per pulse is proportional to the trap length and electron current.
Ion charge state increases with increasing confinement time.
Charge per pulse (or electrical current) ~ independent of species or charge state!



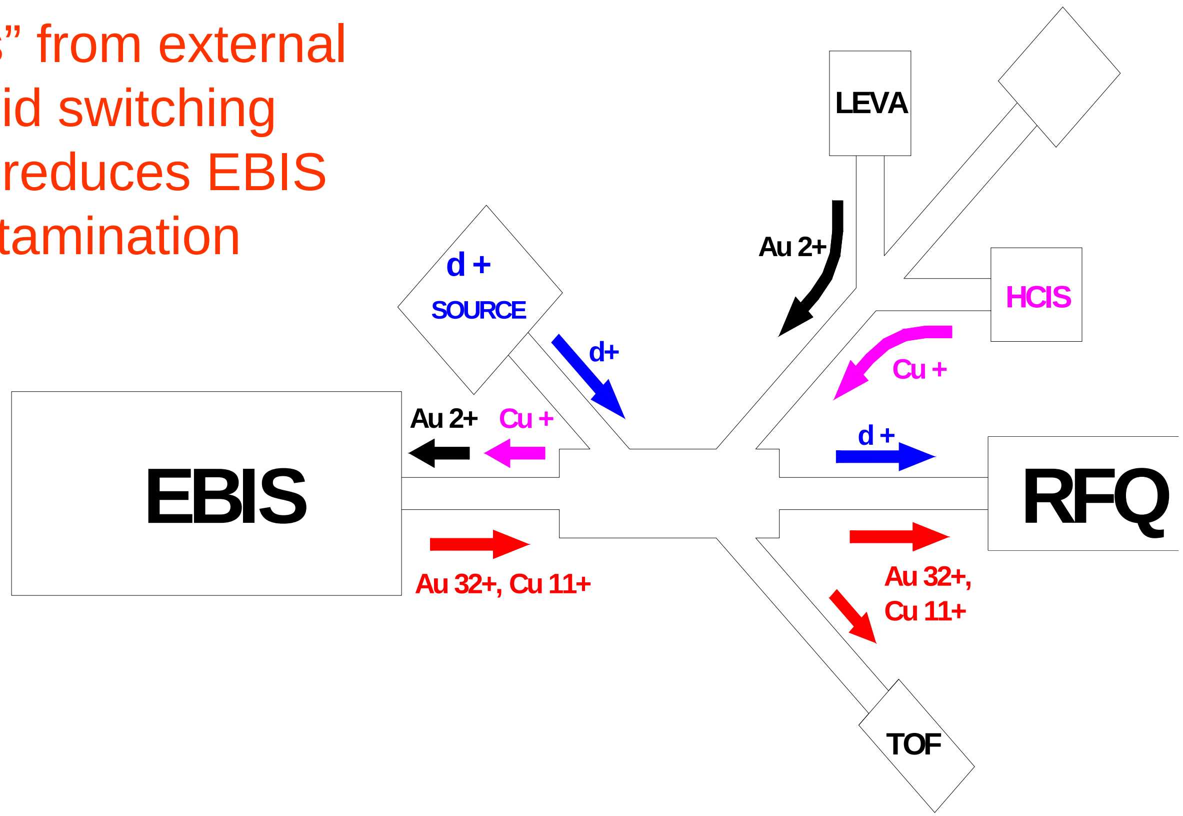
Charge state is selected by choosing the confinement time of ions in the trap

Ions are extracted from an EBIS in pulses of constant charge; one has control over the pulse width



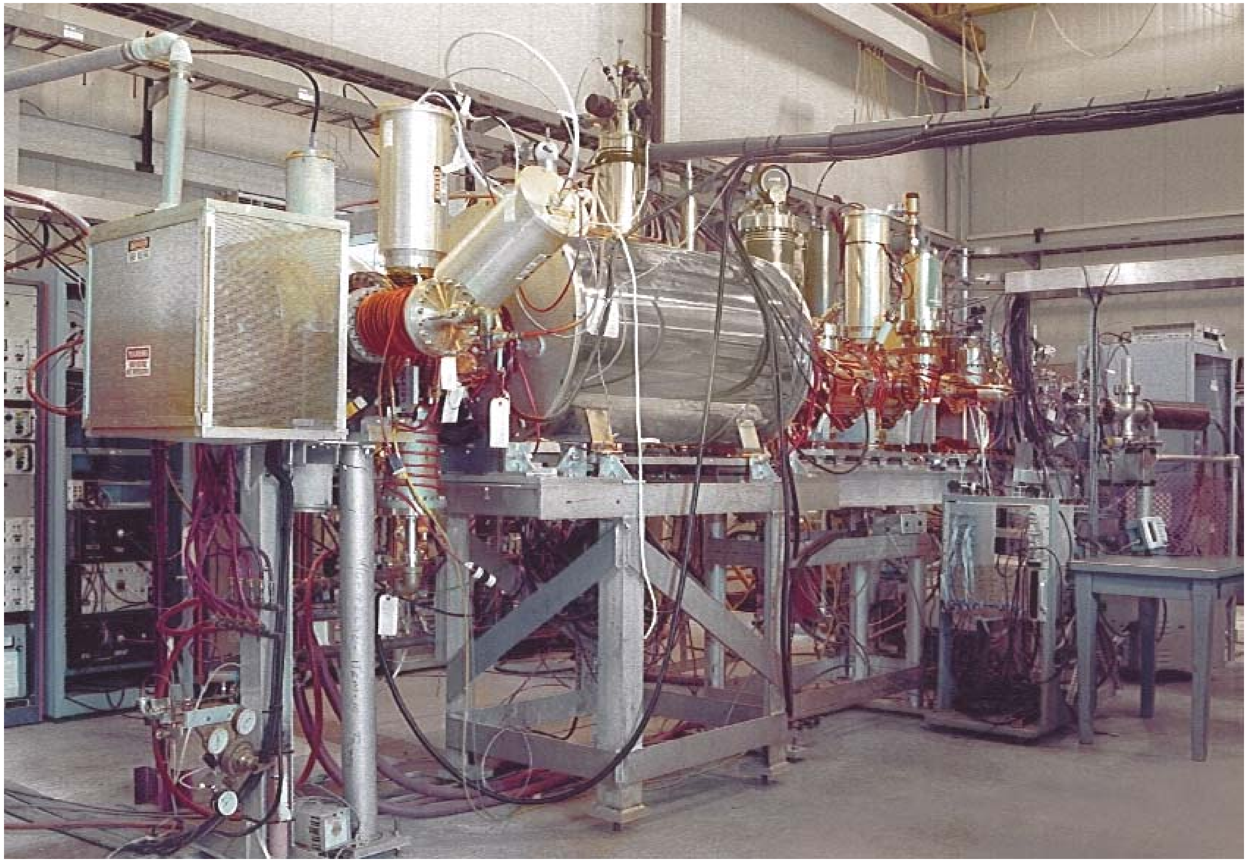
Ion Injection and Extraction from the RHIC EBIS

Injection of “seed ions” from external sources facilitates rapid switching between species and reduces EBIS maintenance and contamination



- EBIS – Electron Beam Ion Source
- RFQ – Radio Frequency Quadrupole Ion Accelerator
- TOF – Time-of-Flight Spectrometer
- LEVA – Low Energy Metal Vapor Vacuum Arc Ion Source
- HCIS – Hollow Cathode Ion Source

Test EBIS

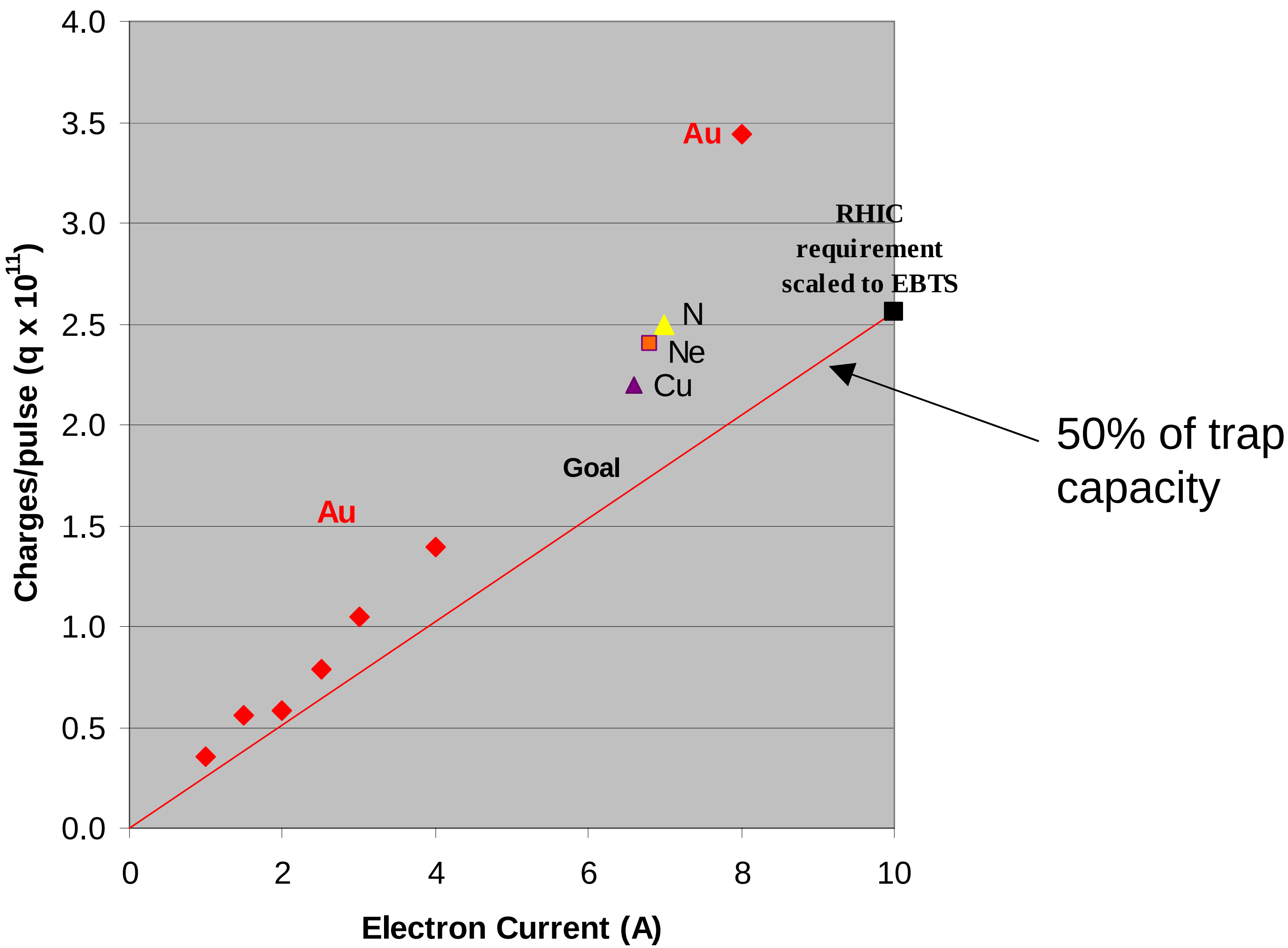


Test EBIS results and RHIC design parameters

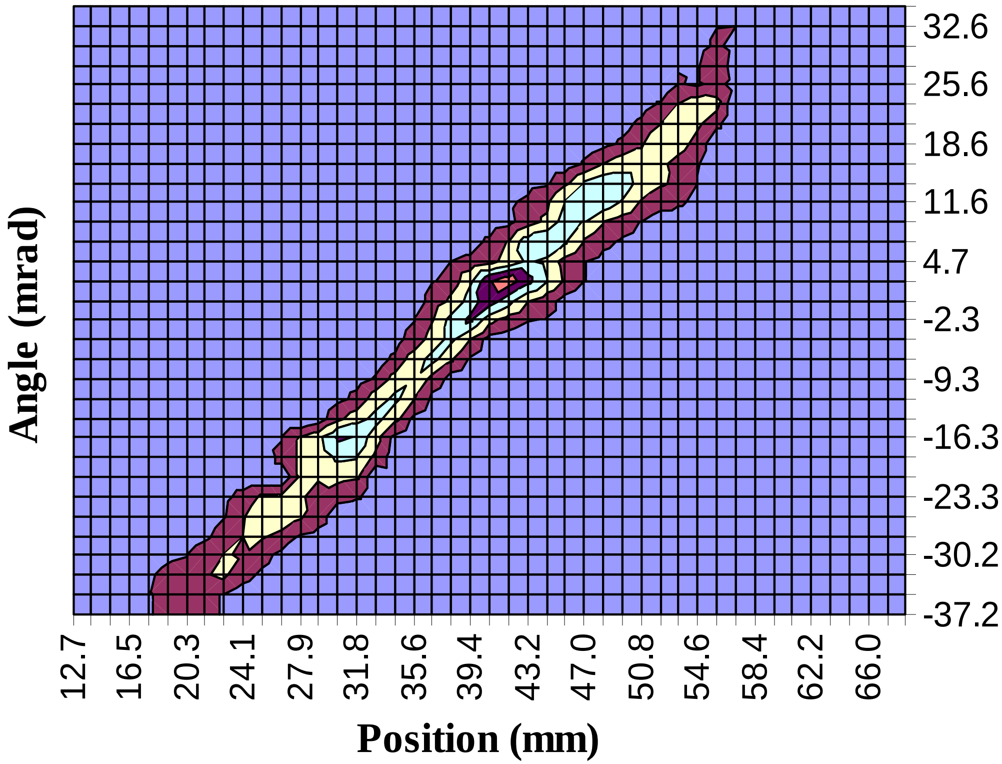
	Achieved	RHIC
Ion	Au^{32+}	Au^{32+}
I_e	10 A	10 A (20)
J_e	~575 A/cm^2	575 A/cm^2
$t_{confinement}$	35 ms	35 ms
L_{trap}	0.7 m	1.5 m
Capacity	0.51×10^{12}	1.1×10^{12}
Au neutralization	70%*	50%
% in desired Q	20%	20%
Extracted charge	55 nC	85 nC
Ions/pulse	1.5×10^9 (Au^{32+})*	3.3×10^9 (Au^{32+})
Pulse width	10-20 μs	10-40 μs

* **Estimated result for data with 8A e-beam**

Charge extracted from Test EBIS



Measured Emittance for a 1.7mA Gold Beam



Emittance of a 1.7 mA extracted beam from EBIS, with Au injection:

ε (n, rms)= 0.1 π mm mrad.

All charge states, peaked around Au^{25+}.

The emittance of light ions from EBIS is expected to be less due to less heating by the electron beam during relatively short confinement times necessary to reach charge states of interest.

Inline Time-of-Flight showing gold charge fraction

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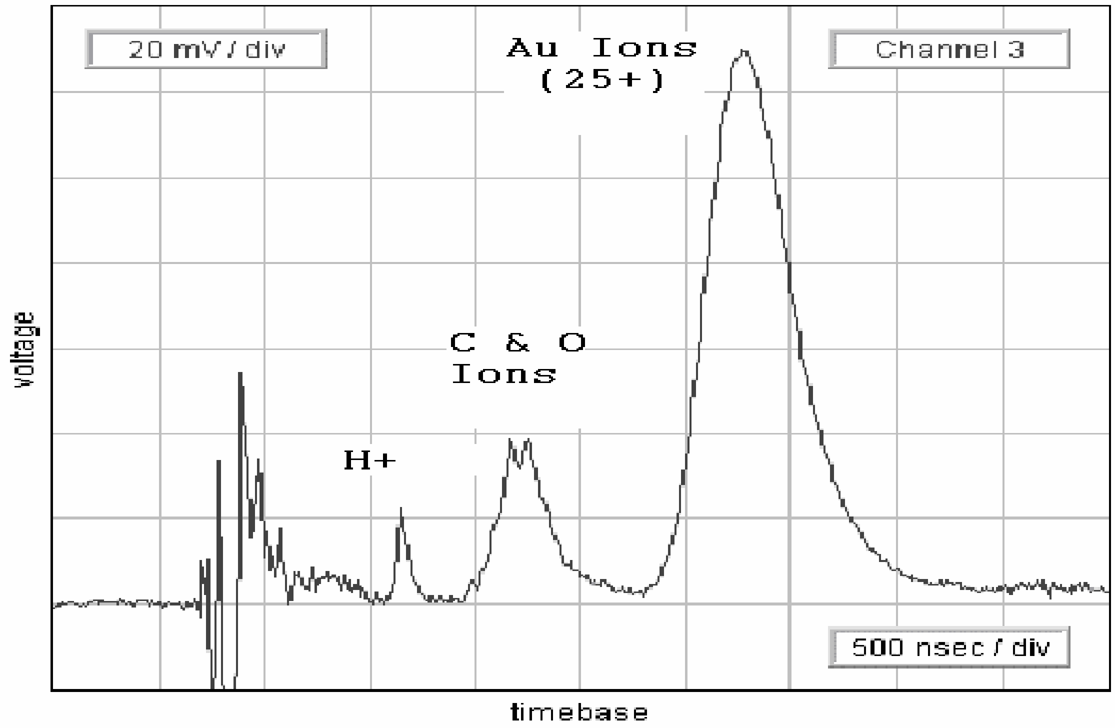

- Full ion beam sampled and collected on Faraday Cup
- I_e= 7A;
- 10 ms confinement
- Au = 83%; C&O = 15%; H = 2%

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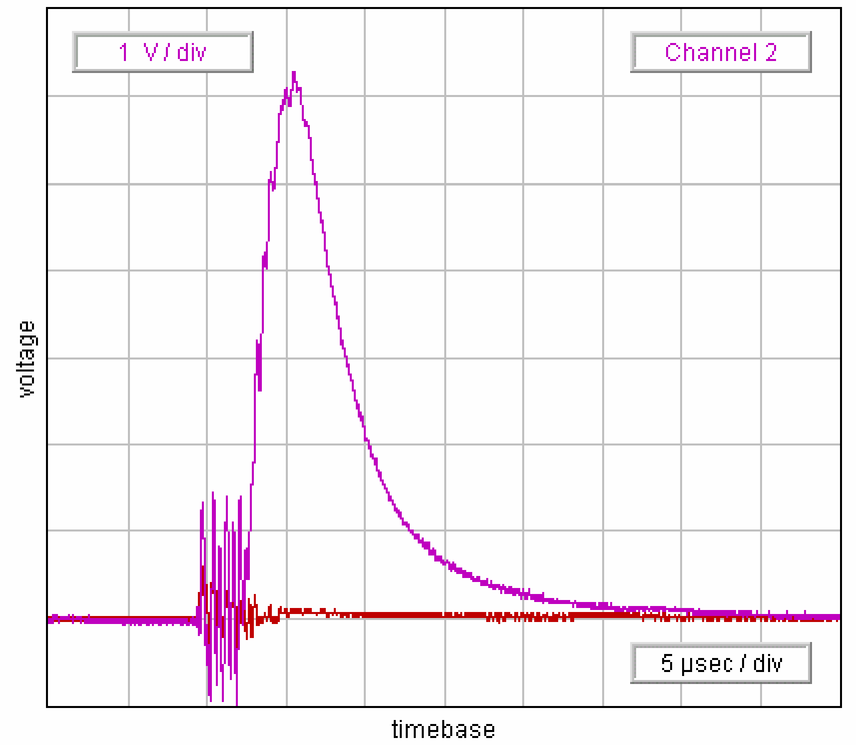
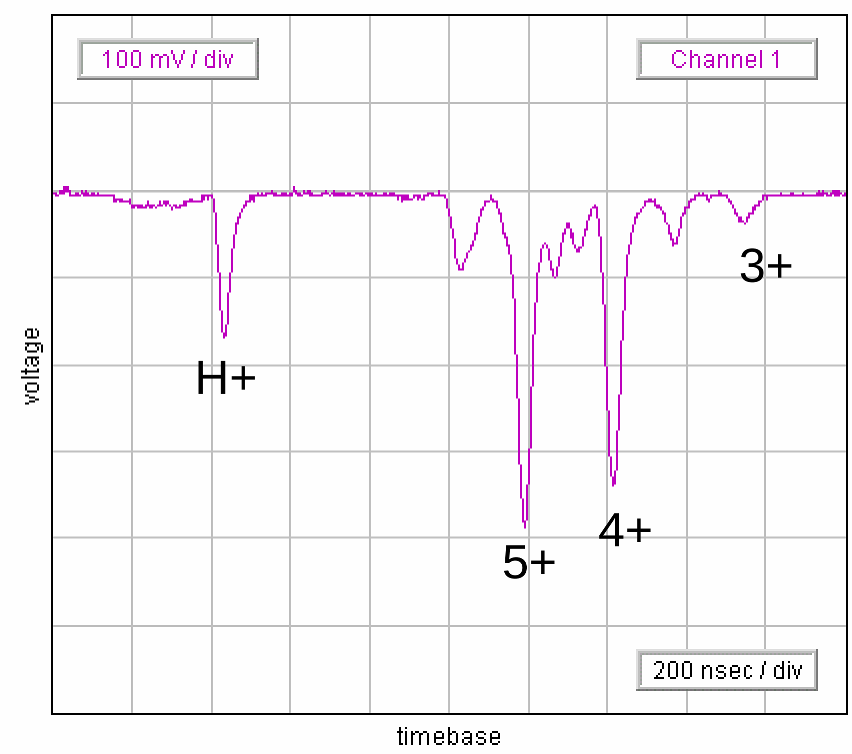
Test EBIS output after Nitrogen injection from HCIS



6 mA total current

2.5 x 10^{11} charges/pulse

N_2^+ injected from HCIS
3 ms injection, 4 ms confinement
I(e) ~ 7A



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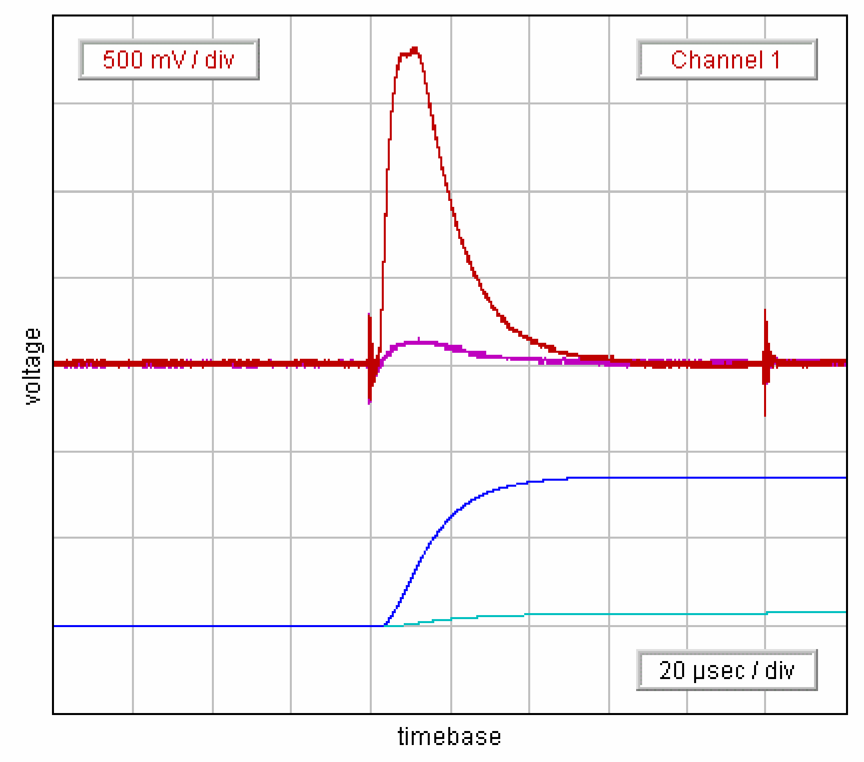
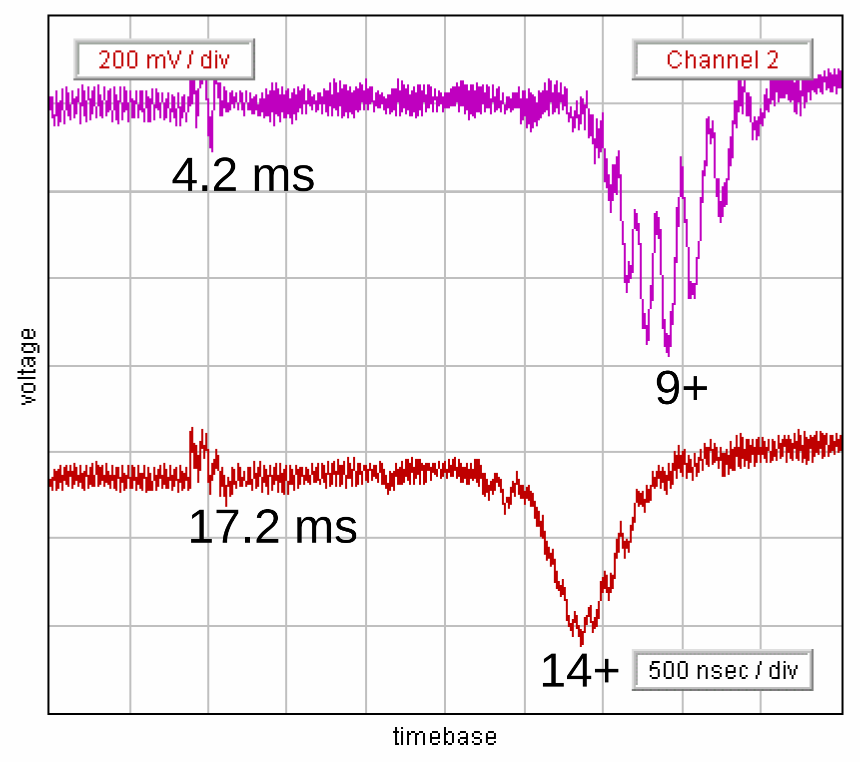
Test EBIS output after Copper injection from HCIS

I(e) = 6.6 A,

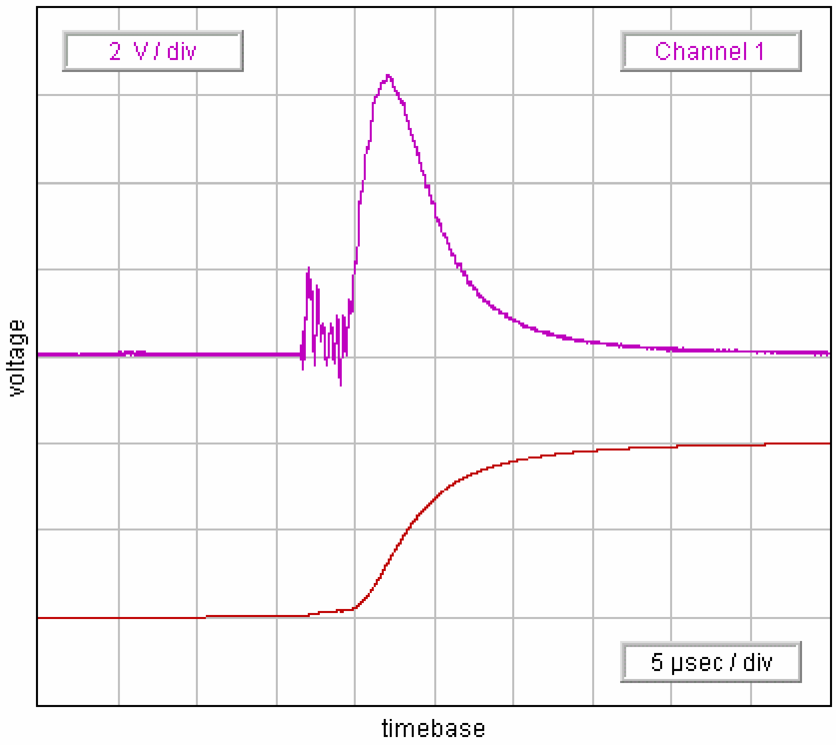




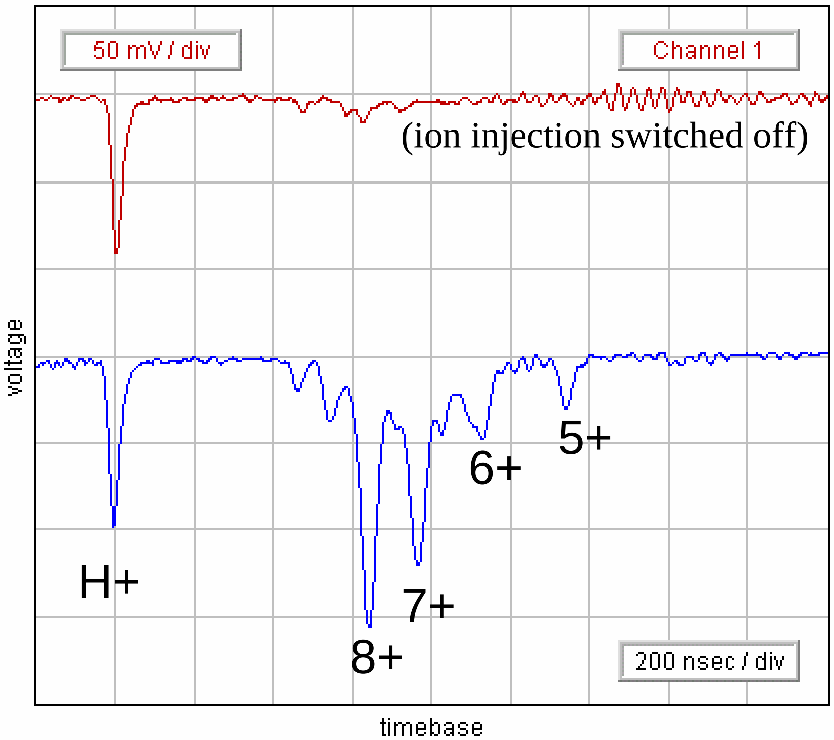
1.8 mA; 2.2x10^{11} charges/pulse,

15.3 ms confinement

Test EBIS output after Neon injection from HCIS



I(e) ~ 6.8 A



6.3 mA peak
2.4 x 10^{11} charges/pulse
18 ms confinement

14 ms confinement

R&D

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We have defined an R&D plan that will aid us in the design of the Low Energy Beam Transport section and reduce schedule risk during the RHIC EBIS construction. This plan also addresses some recommendations from the January technical review.

R&D using the Test EBIS in FY'05/06 :

- Verify Collector design
  - Steps: Build and test RHIC EBIS collector
- Categorize EBIS emittance at final beam energy
  - Steps: Put EBIS on High voltage platform
- Verify LEBT design
  - Steps: Build prototype LEBT and measure emittance at RFQ location

R&D

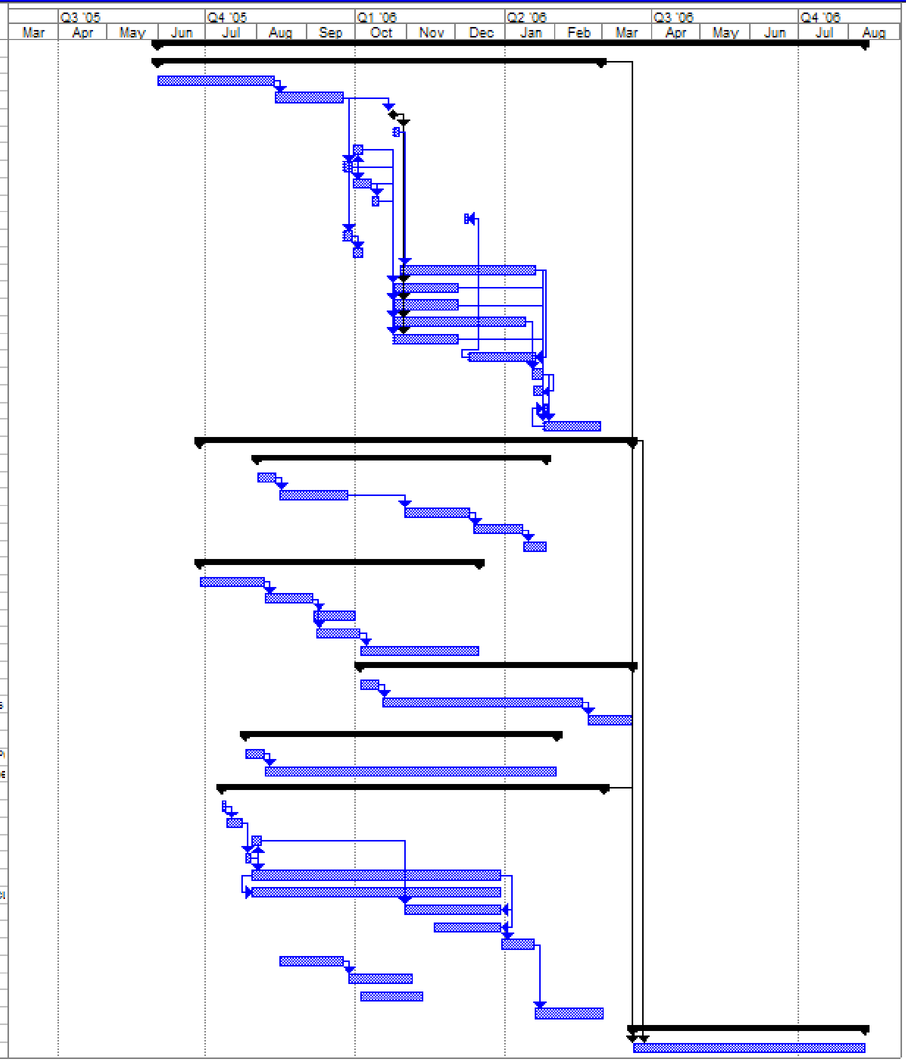
Additional benefits

– Early test of RFQ on Test EBIS
– Use of collector on the RHIC EBIS
– Gain experience with HV pulsing of platform

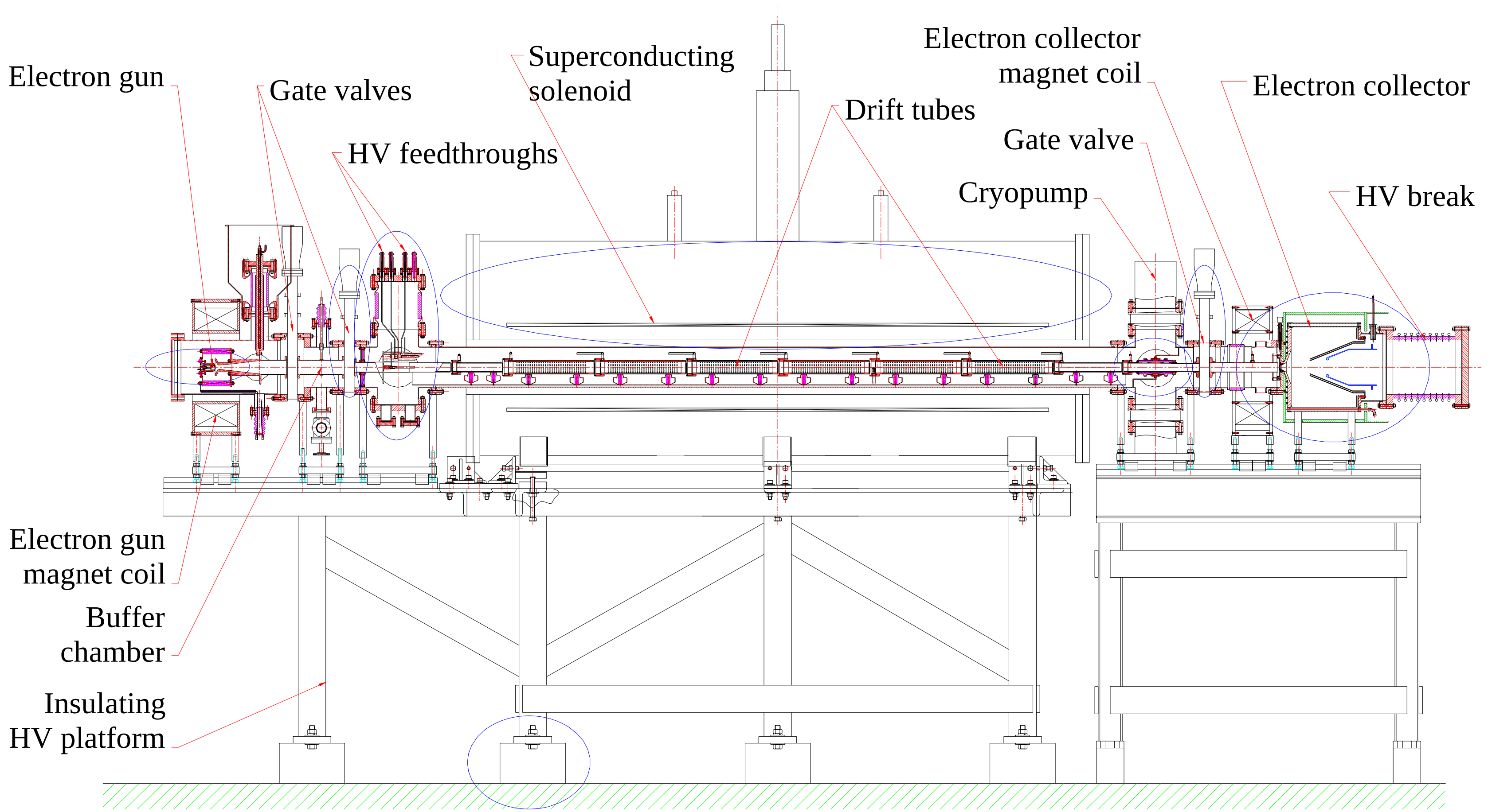
Through this R&D, designs will be verified ~ 2 years earlier than with RHIC EBIS, giving time to make changes if necessary.

R&D Schedule

ID	Task Name
1	**EBIS R&D**
2	**LEBT Chambers, lenses, stand**
3	LEBT physics design
4	LEBT detailed design
5	LEBT money available
6	LEBT chamber procurement
7	Steerer & ps's
8	Deflector design
9	Solenoid design
10	LEBT stand design
11	Procure LEBT feedtroughs
12	Diagnostics prep
13	Diagnostics
14	LEBT chamber
15	Steerer/ps's
16	Deflectors
17	Solenoid
18	LEBT stand
19	Feedthroughs
20	Assemble & test solenoid
21	Solenoid test
22	Prepare LEBT diagnostics
23	LEBT assembly
24	**HV Platform work**
25	**Controls**
26	Platform controls specification
27	Platform controls engineering
28	Controls procurements
29	Platform controls assembly
30	Test platform controls
31	**Platform**
32	Platform / EBIS stand design
33	EBIS platform procurements
34	EBIS platform assembly
35	Fab EBIS stand & caging
36	Install EBIS on platform
37	**HV pulsed power supply**
38	HV ps design
39	HV power supply procurements
40	HV power supply fabrication
41	**Isolation Transformer**
42	Isolation transformer spec & P
43	Isolation transformer procureme
44	**Electron collector/extractor**
45	Solenoid coil design
46	Finalize collector design
47	Insulator spec & PO
48	Collector spec & PO
49	Collector procurements
50	Oversee collector fabrication / proc
51	Insulator procurement
52	Test stand hardware procurements
53	Collector test set assembly
54	Collector ps hardware
55	Collector ps upgrade
56	Post-collector transition piece
57	Collector test & analyze
58	**Testing**
59	Full beam tests



Schematic of EBIS for RHIC



EBIS Source "requirements"

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1. Intensity for 1 x 10^9 Au ions/bunch in RHIC : ~ 3.4 x 10^9 Au^{32+} ions/pulse from the source

2. No stripping before Booster injection : q/m > 0.16 (Au^{32+}, Si^{14+}, Fe^{21+})

3. 1-4 turn injection into Booster : pulse width 10-40 μs

   (Note - 1 & 3 result in a Au^{32+} current of 1.6 - 0.4 mA)

4. Rep rate : ~ 5 Hz

5. Beam species switching: 1 second

6. Emittance : ≤ 0.2 π mm mrad, normalized, rms (for low loss at Booster injection)

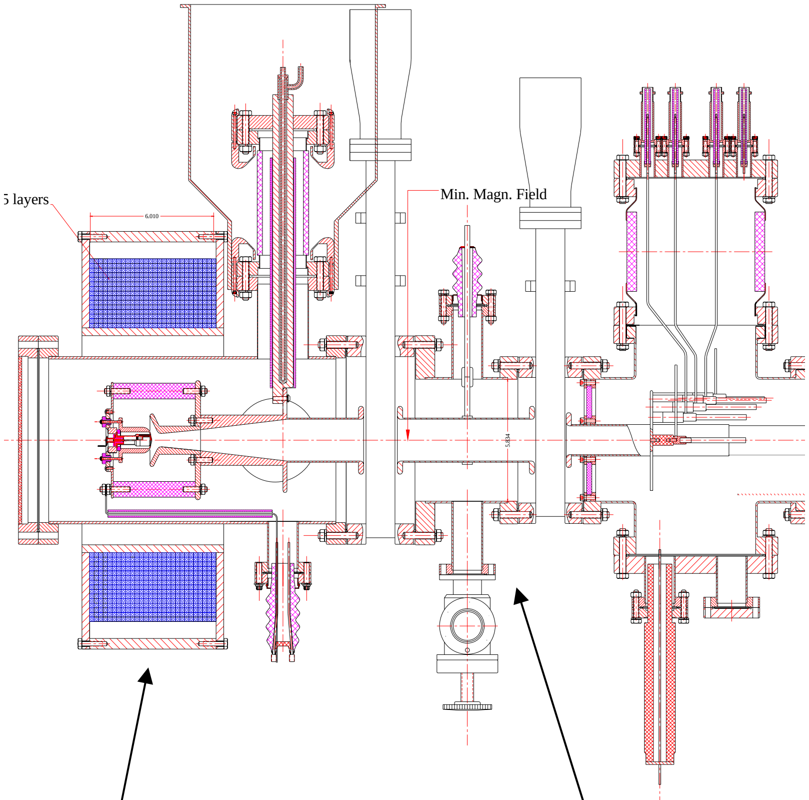
WBS Items

- Superconducting Solenoid
- Electron Gun (up to 20A)
- Electron Collector (300kW peak power)
- Drift Tube & Chamber Structures
- Stands and Platform Hardware
- LEBT
- External Injection

RHIC EBIS Superconducting Solenoid (SCS)

- Length of the SCS coil: 200 cm Test EBIS: 100cm
- Magnet field: 6 T Test EBIS: 5T
  - provides the same magnetic compression of a 20 A electron beam as for 10 A beam
  - decreased average power on electron collector
  - increased magnet field in transport region outside solenoid
  - higher ion charge states if necessary
- Warm bore inner diameter: 204 mm (8”) Test EBIS: 155mm (6”)
  - 1.7 times increased vacuum conductance
  - more room for HV leads
- This item will be provided by a vendor

Gun and gun transition regions



Electron Gun Chamber with Launching Solenoid

Buffer Chamber with Pump-out port

Gun Transition Chamber

- Replaceable electron gun chamber:
  - Minimized vacuum disturbance
  - Pre-conditioned electron gun
  - Fast turn around times
  - Increased EBIS reliability

Electron Gun

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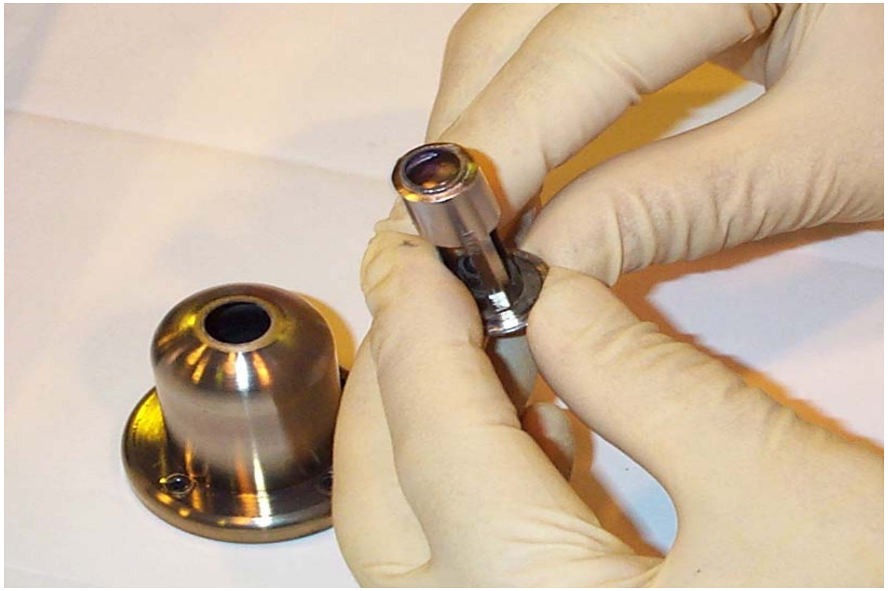
- The existing 10 A electron gun with IrCe cathode meets the RHIC EBIS requirements, with an estimated lifetime of >20,000 hours.

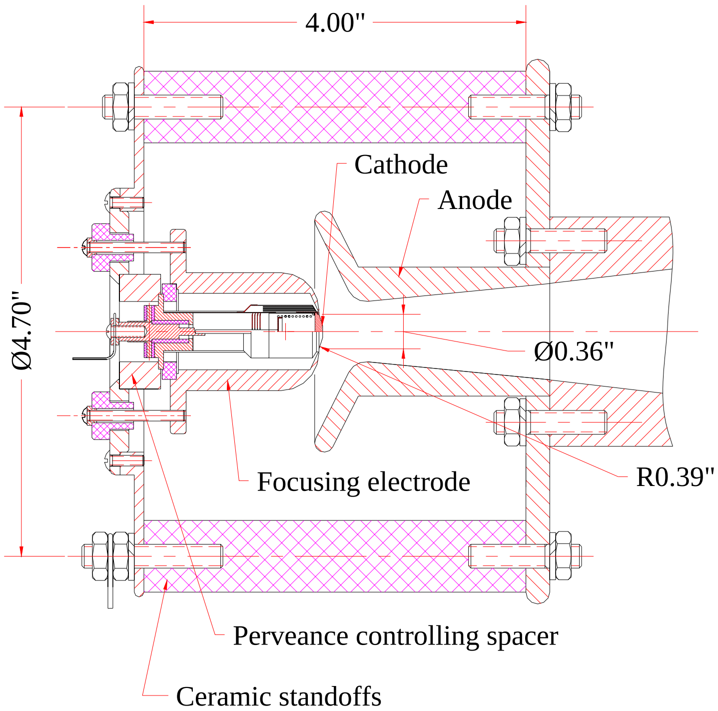
- The present cathode is actually capable of operating at 20 A with lifetime of 3000-5000 hours.



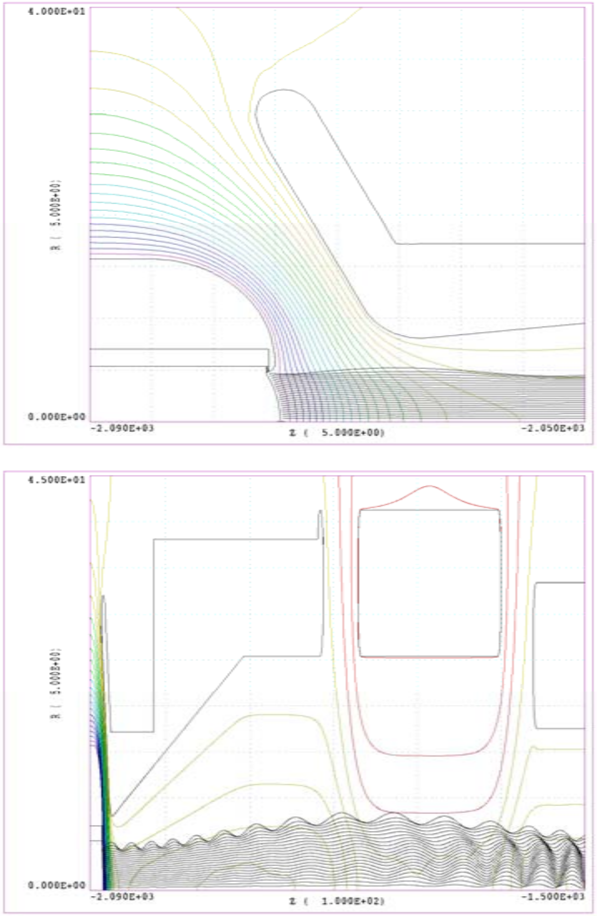
In order to have a reserve for a possible future increase of the ion beam intensity, we are building the electron gun electrodes and collector with the capability of operating up to 20 A.

Electron Gun Design

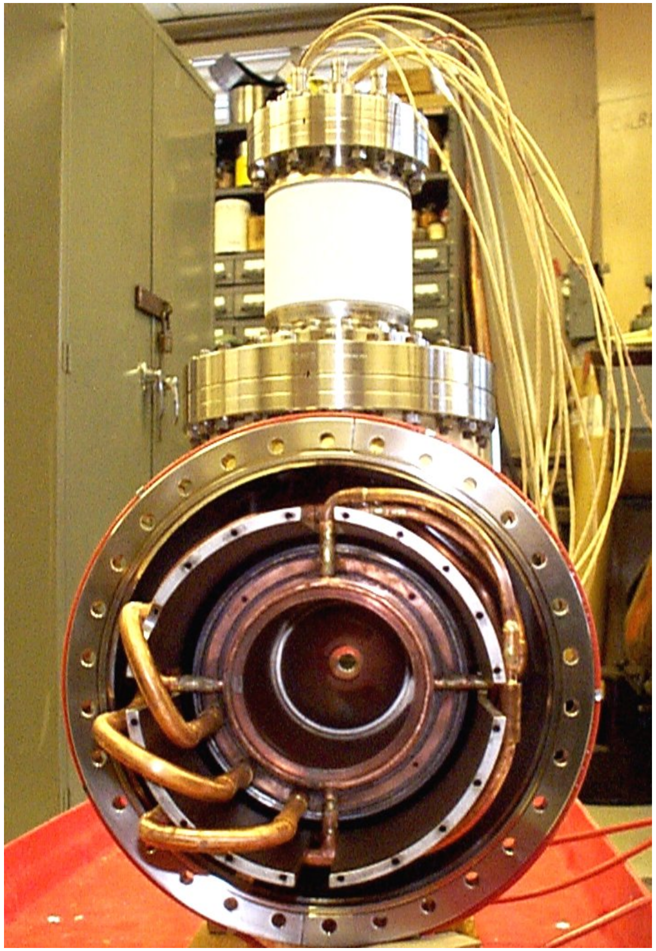
Electron gun



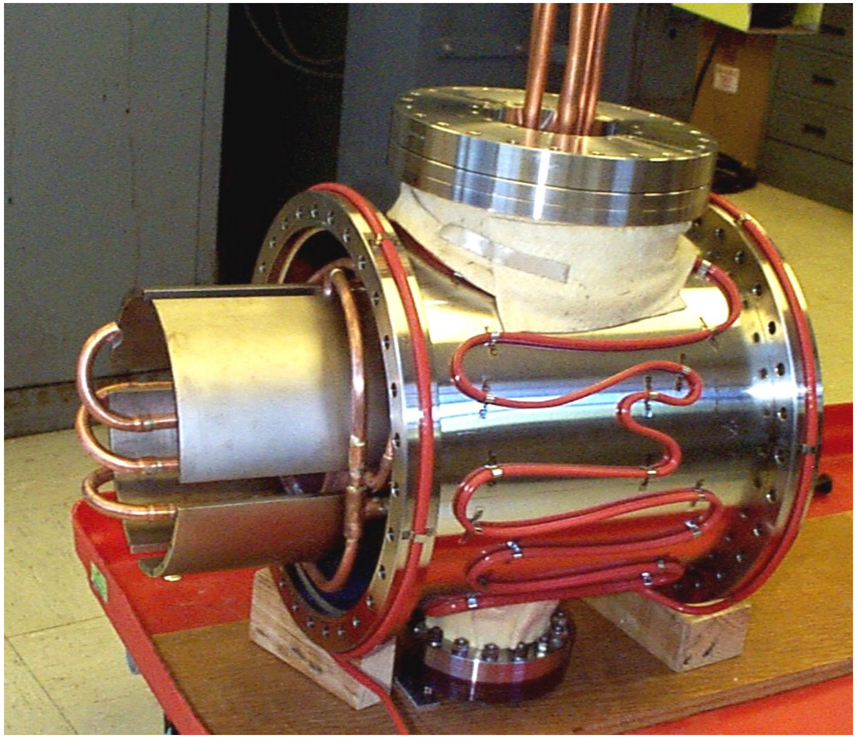
Electron beam transmission from the electron gun.
Iel=20.5 A, Ua=38.5 kV



Test EBIS 50kW Electron Collector

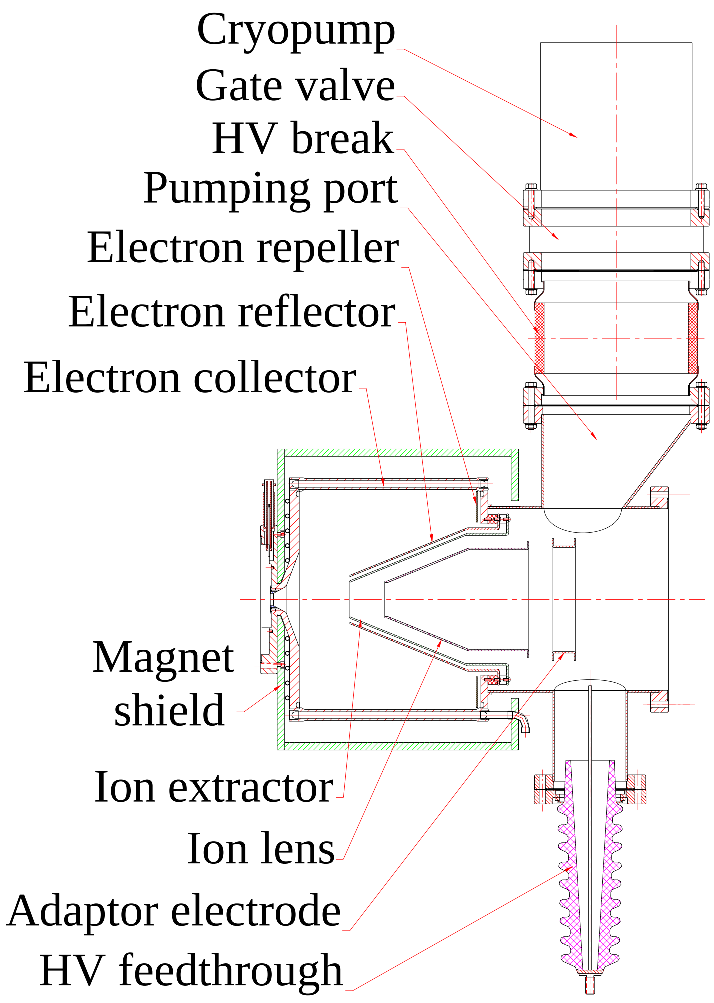


View from ion extractor end
(extractor not installed)



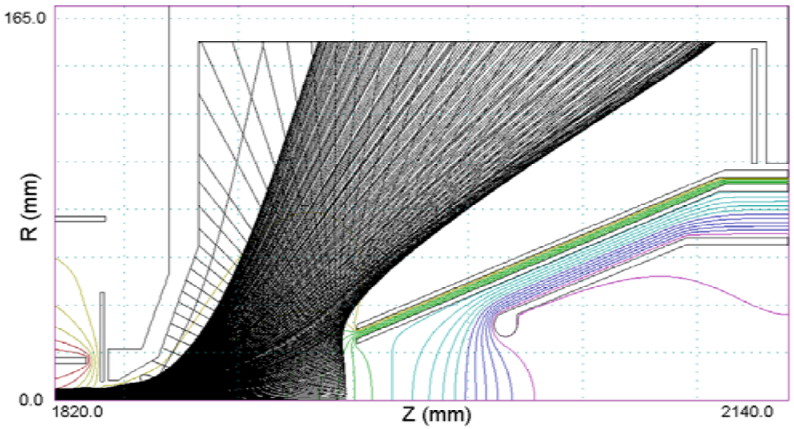
Electron Collector and Vacuum Housing

RHIC EBIS electron collector assembly design

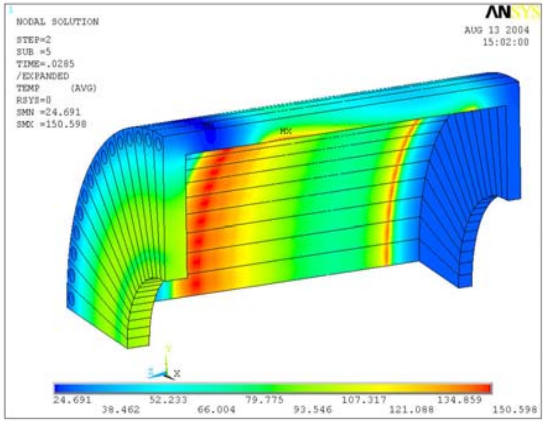


- Designed to dissipate P_{el}= 300 kW peak power
- More uniform distribution of e-beam
- Increased surface area (2300 cm^2)
- Calculated max power density on EC surface (for 300 kW): p_{max}= 485 W/cm^2
- Outer surface of collector is at atmosphere (no internal cooling lines).

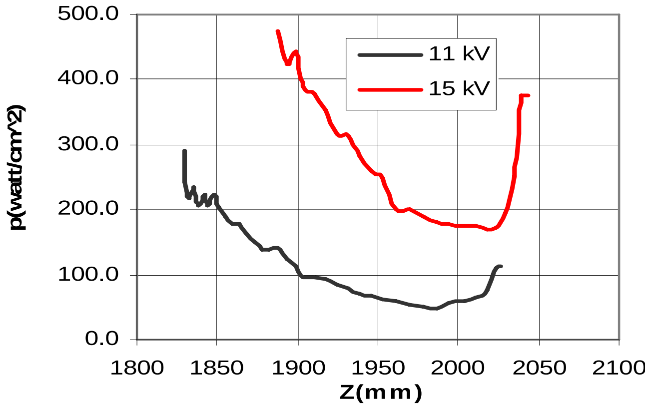
Simulations for 20A, 15keV electron beam



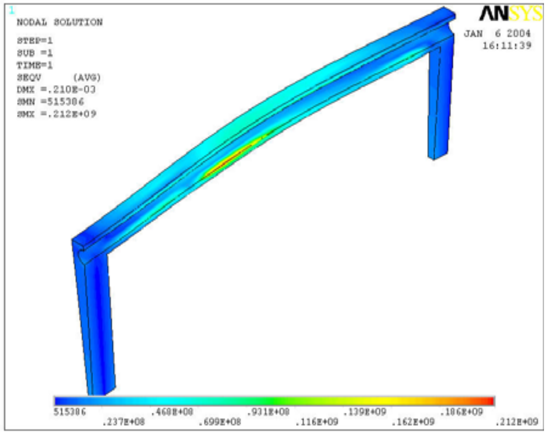
20A electron beam trajectories in EC



ANSYS simulation of temperature distribution in EC at peak power. 20 A, 15 kV, 50% DC



Electron beam power density distribution on EC surface

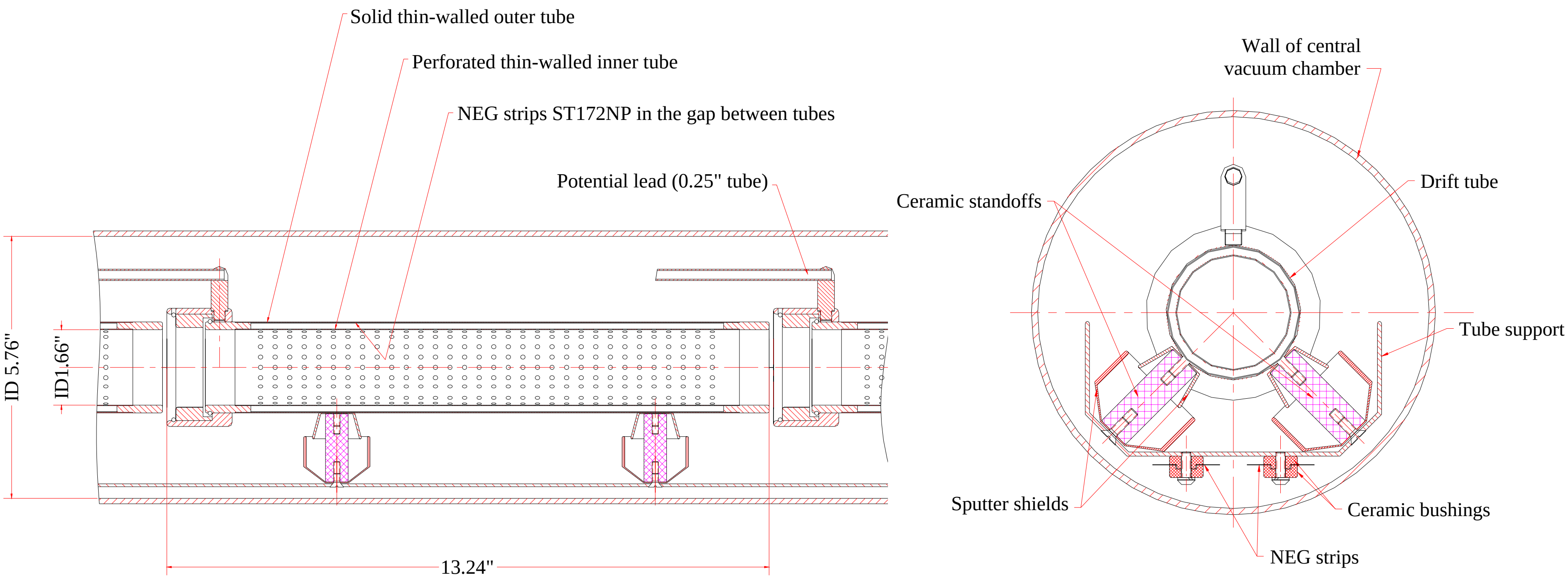


Von Mises stress distribution at peak power

Electron collector simulation results and status

- RHIC EBIS electron collector was designed and simulated for **300 kW** electron beam power.
- After analysis of several EC material we selected Brush Wellman **copper-beryllium alloy Hycon-3**, because it has the largest margin between the yield stress and the resulting stress.
- ANSYS stress simulations demonstrate, that for 50% duty cycle (50 ms ON, 50 ms OFF) and 15% duty cycle (30 ms ON and 170 ms OFF) the average values of stresses and their amplitudes provide **life time before fatigue failure well over 10^8 cycles.**
- *The electron collector has had a design review and is expected to be ordered from Brush Wellman in about a month.*

Central Drift Tube Structure



Similar to existing Test EBIS drift tube structure.

Design in advanced stage, detail for adjustable mounts needs work.

Test EBIS Drift Electrode Structure

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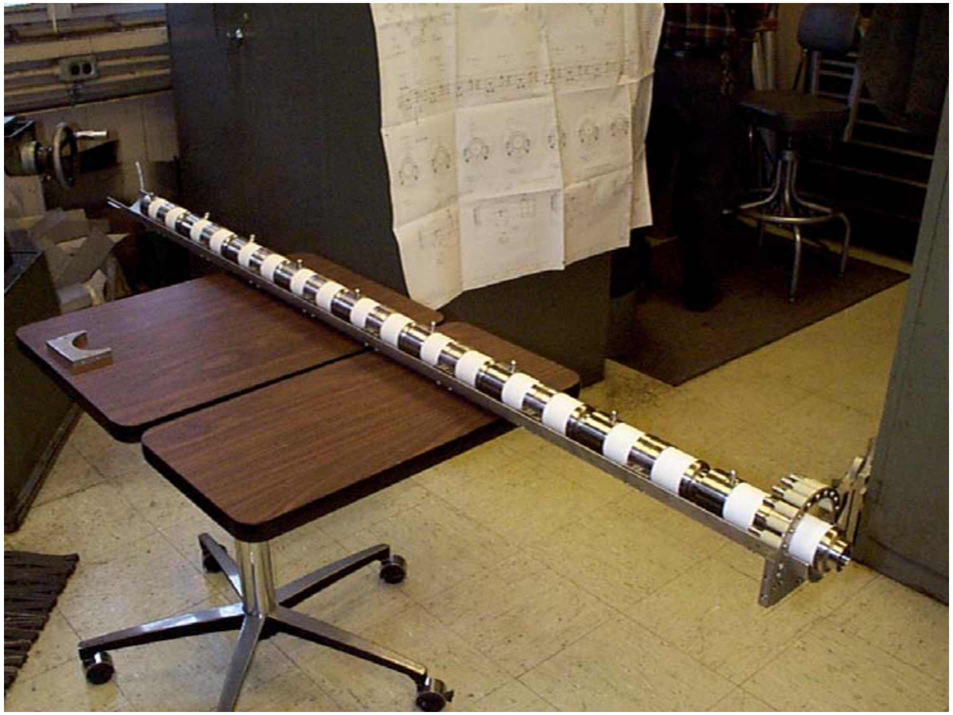

- Drift electrode structure spans the length of the central vacuum chamber within the Test EBIS Superconducting Solenoid bore

Close-up of electrical leads

LEBT (hardware view)

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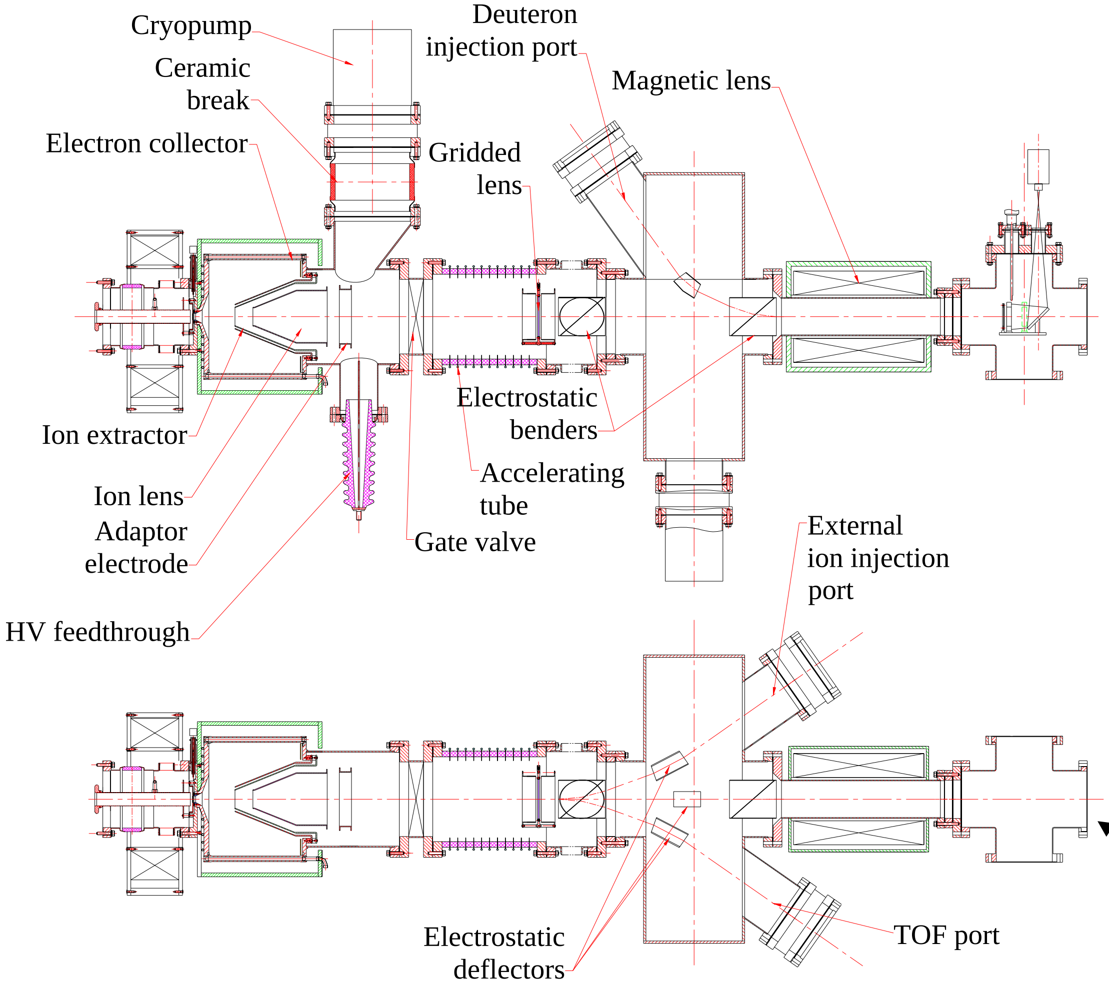
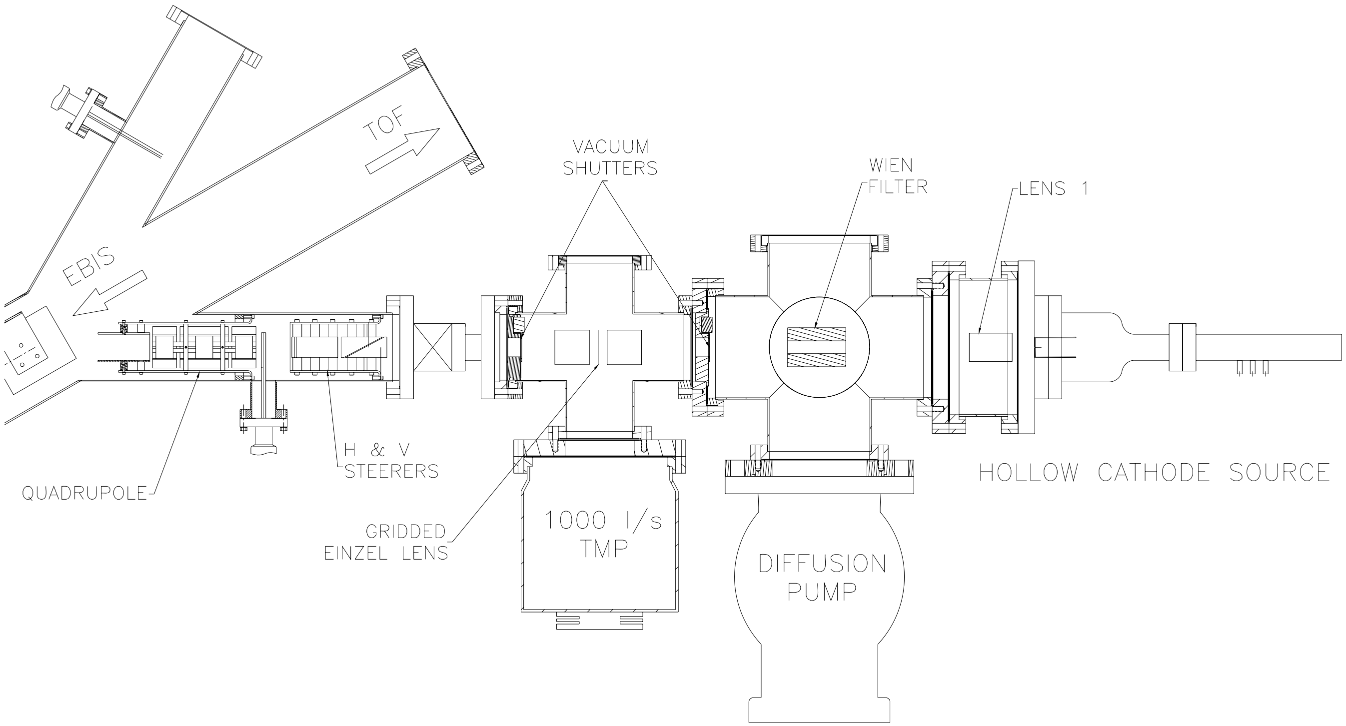


- Beam switching in the injection line and LEBT is made in electrostatic bender switchyards

  Emittance measurements will be made in a removable test chamber at the end of the LEBT before the RFQ arrives

Emittance measurement chamber (removable for LEBT attachment to RFQ)

Hollow cathode source pumping and ion optics



P~4x 10-8 mb P~4x 10-6 mb P~8x 10-5 mb P~0.8mB

P_{EBIS}~2x10^{-10} mb for P_{HCIS}~1mb, 10ms, 1Hz shutter operation

"Seed ions" will be provided from relatively low cost ion sources which have been tested and developed to meet our needs in our laboratory.

LEBT Layout showing External Ion Injectors and HV Platforms

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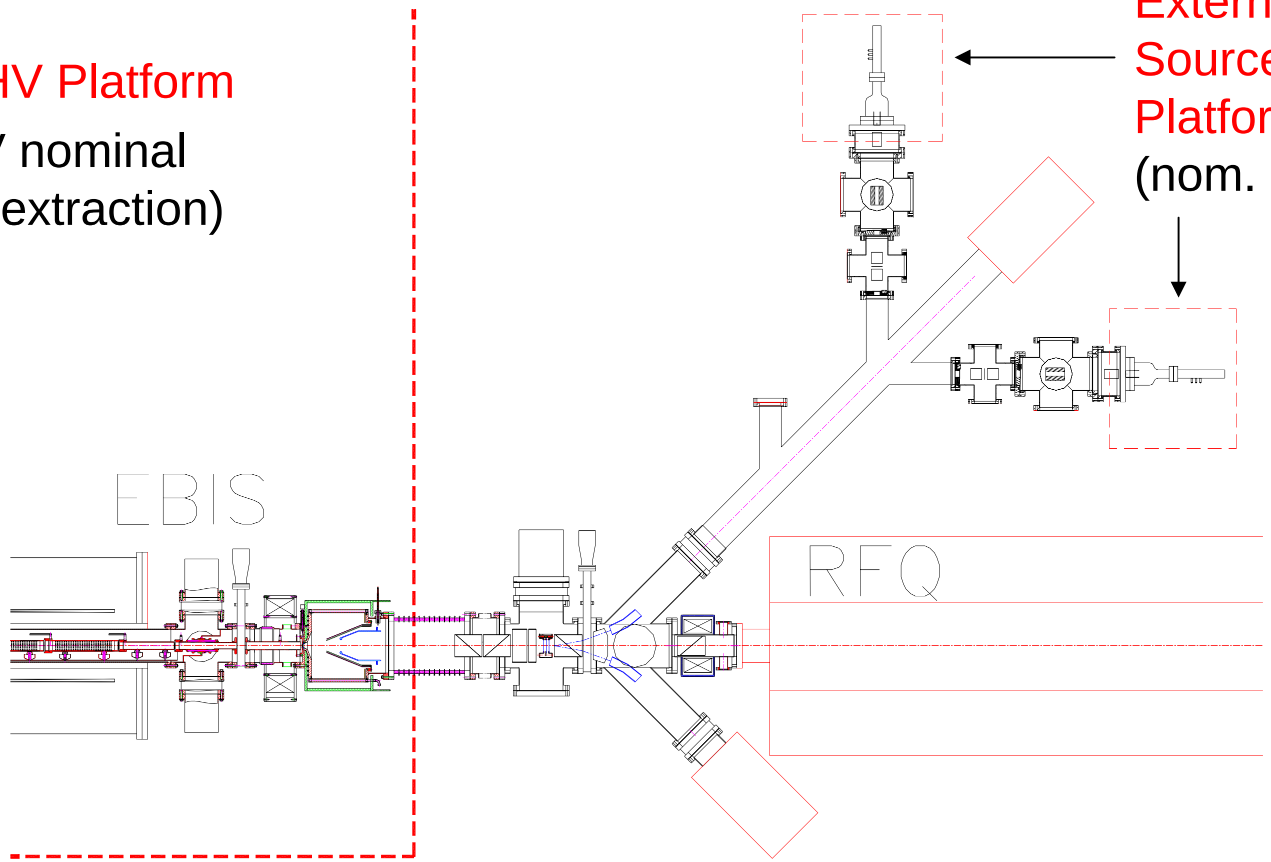
EBIS HV Platform

(100kV nominal during extraction)

External Ion Source Platform(s) (nom. 20kV)



EBIS Platform: 0V during Ion Injection and confinement; 100kV during ion extraction

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External sources used for primary ion injection at the Test EBIS

Low Energy Vacuum Arc Source (I. Brown); used very successfully for Au injection

Hollow Cathode Ion Source (HCIS), based on design used on Saclay EBIS.

Discharge current = 0.5 - 4 A
Plasma electrode diameter = 1 mm
V(extraction) ~ 15 kV
Source has produced:

- 45 μA of Cu^+
- 130 μA of Ne^+
- 27 μA of N_2^+.

These currents are sufficient for seeding the EBIS trap.

Comments on Schedule

- Components of the RHIC EBIS will be designed, manufactured or procured. Assembly in a temporary location will then start in mid-FY'07.
  - This will allow testing of vacuum and high voltage (no beam testing is planned)

- The EBIS will be moved to its final location as a unit, in Q1, FY'08.

Procurements / fabrication (R&D)

- Full power electron collector (later used on the final EBIS)
- High voltage isolation transformer (later used on the final EBIS)
- High voltage insulating break
- Controls for the EBIS HV platform ps's
- Platform components
- LEBT chambers, solenoid, components
- Prototype pulsed HV power supply

EBIS R&D costs

- **Estimated Costs**

Description	Direct FY'05K$			
	Mat'l	Labor	Contingency	Total
R&D	345	383	$145 (20%)	873

Costs for the EBIS construction and testing will be presented in the detailed talks tomorrow.